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INVESTIGATION OF ELECTRON IMPACT PROCESSES RELEVANT TO VISIBLE LASERS

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FOREWORD

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6. Glow Discharge Source
7. Charge Exchange Source

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

During this contract period the noise background in the electron spectrometer has been reduced to an acceptable level. Two parallel efforts are currently underway to investigate and optimize metastable rare gas atom production. A glow discharge source has been constructed which produces of the order 10^8 cm^{-3} argon metastable atoms within the collision volume intercepted by the electron beam. Electron scattering experiments are currently underway using this source. In addition the ion current capabilities of a Duoplasmatron ion source are being explored with a view to potential application to a charge

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) transfer source of metastable rare gas atoms. The projected metastable density achievable from such a system should be of the order 10^{10} cm^{-3} which represents two orders of magnitude improvement over the presently employed glow discharge source.

10 to the 10th power/cu.cm.

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I. INTRODUCTION

The role of the AERL Electron Kinetics program in the DARPA/ONR sponsored AERL visible laser program is to supply relevant electron kinetics data necessary for modeling and optimizing laser performance specifically in the important areas of the KrF scaleup, the excimer laser research program and the area of small-scale discharge studies.

The advent of techniques developed at AERL for scaling electric gas discharges to large volumes and to high volumetric pumping rates revealed a considerable lack of electron scattering, cross section data required to model and, hence, understand these discharges. In particular, since these discharges are often characterized by very high electron pumping rates in order to achieve laser systems capable of being scaled to high-average power, then the fraction of excited species is large and electron collisions with such species is known to play a major role in affecting the overall electron kinetics of the discharge.(1)

Due to the problems associated with the preparation and manipulation of excited atomic and molecular species for the purposes of performing electron collisions experiments and also due to the previous lack of any important practical application of the data, the total data available describing such collisions is rather meager. The situation has improved somewhat

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(1) "KrF Laser Research," AERL 804, April 1976.

recently as a growing recognition of the practical importance of these processes develops.[2-6]

The present AERL Electron Kinetics program was proposed in order to provide absolute cross section data, particularly with regard to collision processes between electrons and excited atomic and molecular species. The program consists of parallel and complementary experimental and theoretical efforts. Results from these combined program efforts will yield reliable absolute cross section data covering the range of electron energies encountered in the electric discharges of interest (0.2 to 20 eV).

If exercised independently, neither technique can provide such complete information with regard to cross sections for scattering from excited state.

In addition to the complementary benefits offered by the experimental and theoretical efforts, each has certain capabilities not shared by the other. For instance, the theoretical effort is not restricted to metastable excited species as is the experimental technique. It can also be applied to allowed transitions from excited species, which can also reach high densities in the discharge due to radiative trapping and hence effectively exhibit metastable properties. The experimental program on the other hand can handle processes

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(2) Long, D.R. and Geballe, R., Phys. Rev. 1, 260 (1970).

(3) Lake, M.L. and Garscadden, A., 28th Gaseous Electronics Conference Rolla, Mo. (1975), Paper C-5.

(4) Mityurwa, A.A. and Penkin, N.P., Opt. Spectrosc. 38, 229 (1975).

(5) Wilson, W.G. and Williams, W.L., J. Phys. B9, 423 (1976).

(6) Tannen, P.D., "Cumulative Ionization and Excitation of Molecular Nitrogen Metastables by Electron Impact," Dissertation (1973), School of Engineering, Air Force Institute of Technology.

in ground state or metastable molecular specieis for which accurate wave-functions are not available and are therefore not amenable to the theory.

The experimental apparatus which is described in Section II employs the crossed beam technique combined with an electron spectrometer in order to perform electron energy analysis for diagnostic purposes.

The theoretical effort utilizes both semi-classical and quantum-mechanical methods to calculate the relevant cross sections. The details of the theoretical approach will be discussed in Section III.

The rare gas monohalide laser systems which have been the subject of extensive experimental and theoretical investigations at AERL within the past year[7,8] have emerged as extremely promising candidates for satisfying certain goals of the DARPA visible laser program. These studies have identified electron collision processes with metastable states of the rare gas atom constituents as playing major role in both discharge stability and in determining the equilibrium metastable concentration, which through reaction with the halogen molecule leads to excimer formation.

A detailed analysis of the influence of the rare gas metastable density on the efficiency and discharge stability of the KrF excimer laser is given in a recent AERL proposal prepared for DARPA/ONR "KrF Laser Research," AERLP 804, April 1976.

At present no information exists regarding electron collision processes with the rare gases of interest (Ar, Kr and Xe). The processes in question are excitation to more highly excited states and ionization. This program was proposed in order to study both types of process and to supply

(7) Ewing, J. J. and Brau, C.A., Appl. Phys. Lett. 27, 350 (1975).

(8) Ewing, J. J. and Brau, C.A., Phys. Rev. A 12, 129 (1975).

cross section data from both metastable excited states and excited states which are optically connected to the ground state.

Examples of the transitions of interest are indicated in the partial energy level diagram of Krypton shown in Figure 1 and for Argon shown in Figure 2. The only theoretical calculations available for transitions of the type shown in Figures 1 and 2 which cover the energy range of interest for laser modeling are those of Burke et al. for the He atom. The transition corresponding to those shown in Figures 1 and 2 are shown in Figure 3 they are $2^1S \rightarrow 2^1P$ and $2^3S \rightarrow S^3P$ transitions. The important feature of these cross sections is the extremely large magnitude, $\sim 10^{-14}$ cm^2 which supports our contention that the corresponding transitions between the first two excited states of the other rare gases should be extremely large.

ELECTRON IMPACT PROCESSES RELEVANT
TO THE KrF LASER

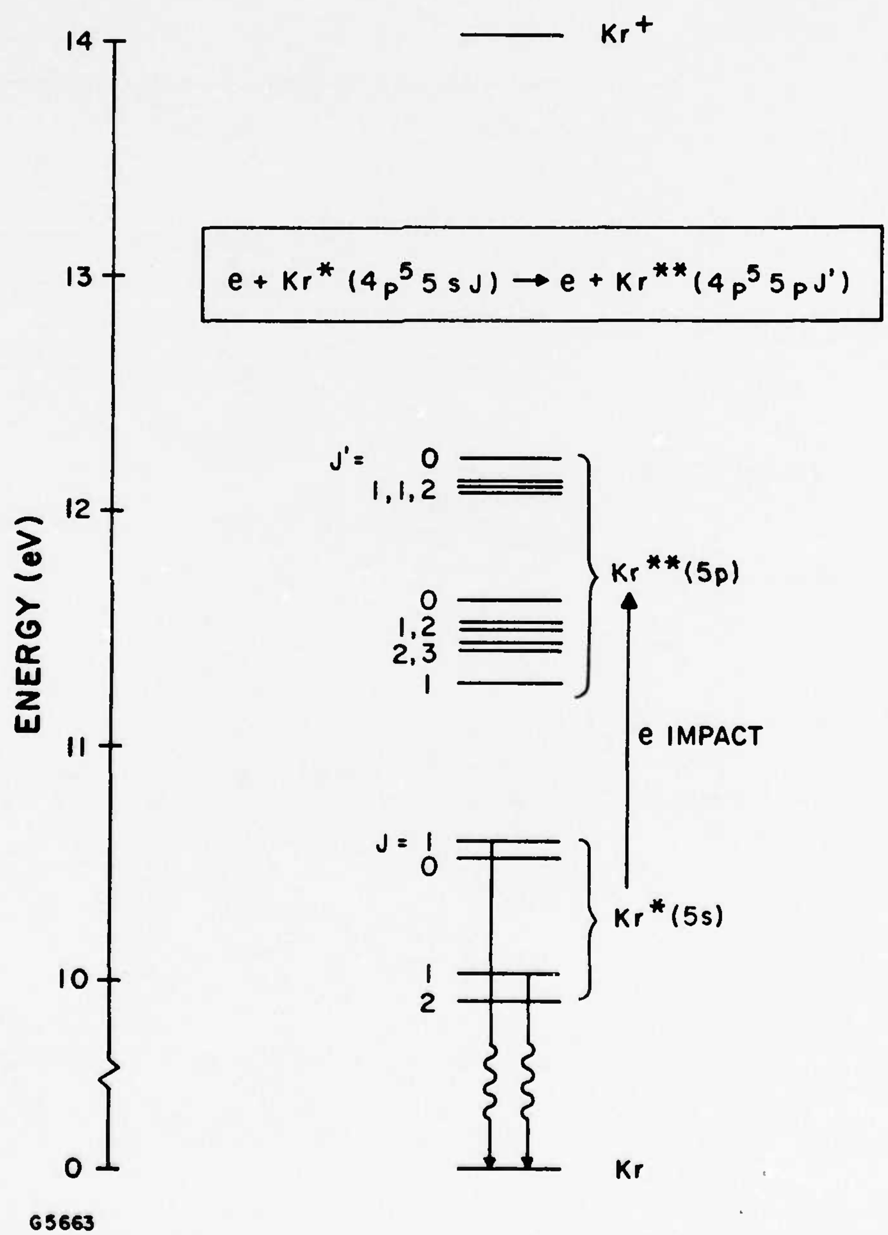


Figure 1 Partial Energy Level Diagram of the Krypton Atom Indicating Transactions Between the First Two Excited State Manifolds

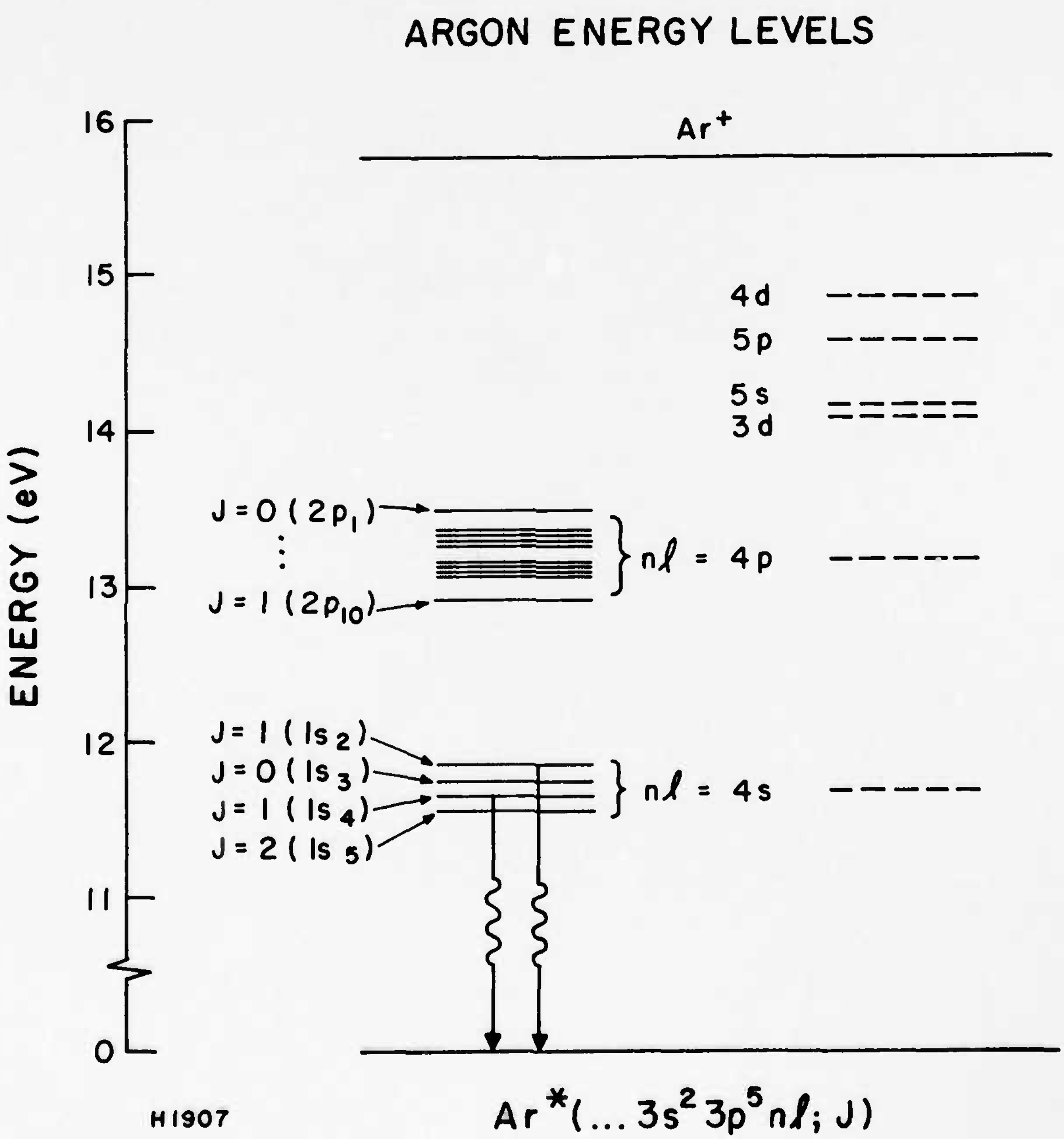


Figure 2 Partial Energy Level Diagram of the Argon Atom Indicating Transitions Between the First Two Excited State Manifolds

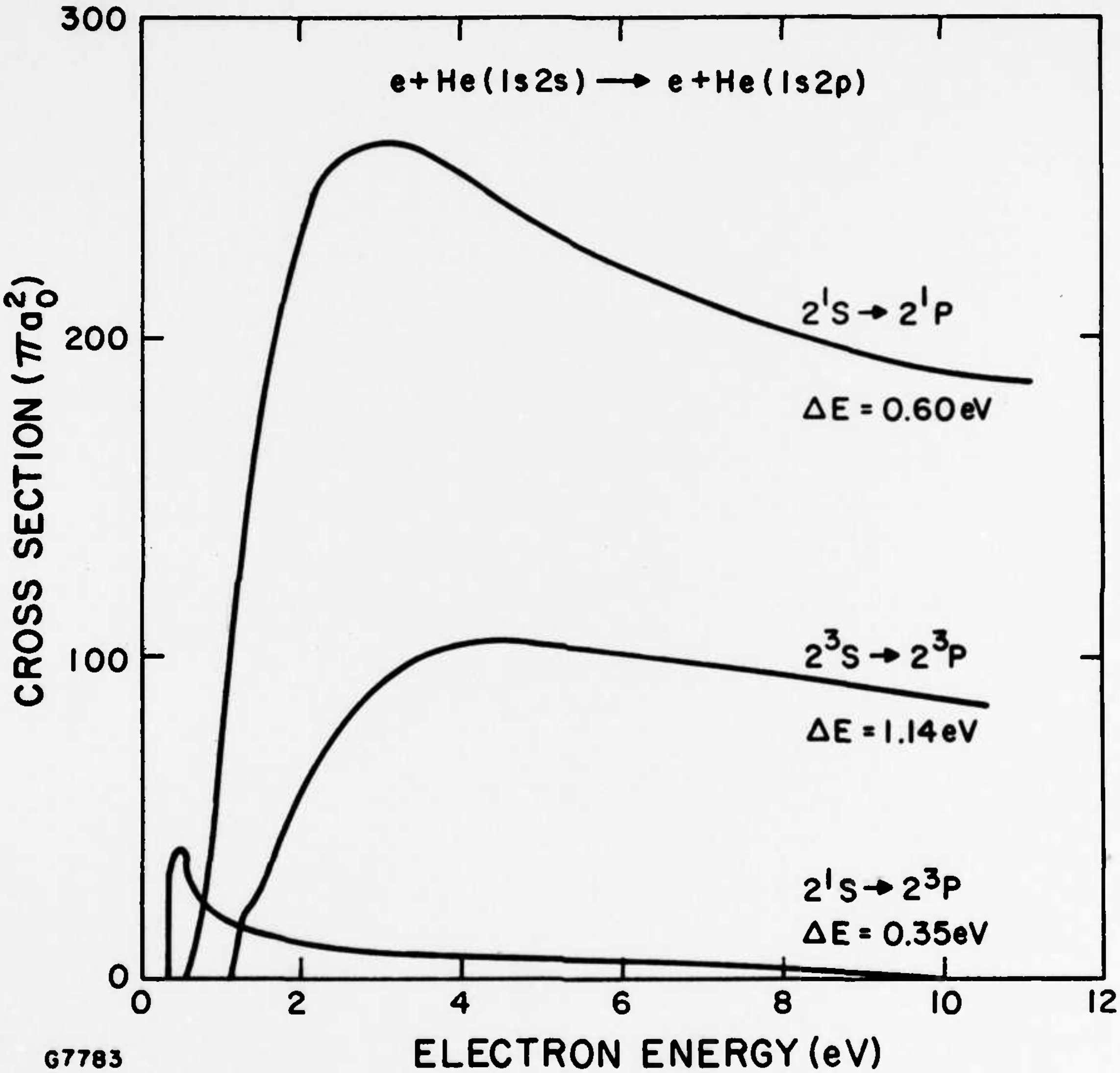


Figure 3 Close Coupling Calculations for Excitation Between the n States of Helium(9)

(9) Burke, P.G., Cooper, J.W., Ormande, S. and Taylor, A.J., Abstract V ICPEAC, Liningrad, (1967).

II. EXPERIMENT

A. TECHNIQUE

The experiment employs the crossed-beam technique, the concept of which is outlined in Figure 4. A low density collimated beam of the atomic or molecular species of interest is collided at right angles with an electron beam of the appropriate energy whose energy spread is small compared with the mean energy. In general, a wide variety of diagnostic techniques can be employed to measure the electron scattering cross sections. The merits of the various methods were discussed at length in the original AERL Electron Kinetics Program Proposal, which concluded that the electron spectroscopy of the inelastically scattered electrons offered the broadest application compared to any other single technique. However, recognizing that an occasion other diagnostics might be preferred or required for certain processes, the apparatus was constructed in such a way as to permit the addition of these refinements without major modification to the system.

Calculations which model electric discharges in gases are insensitive to structure in the various electron excitation cross sections, if it is narrow compared with the width of the electron energy distribution which exists in the plasma. The objective of this program, therefore, is to provide the broad features of the energy dependence of the various excitation cross sections over the energy range of interest, ~0.2 to 20 eV. Since it is unnecessary to employ a high resolution electron beam source, a rather simple design of electron gun is adopted where the emphasis is placed upon intensity rather than resolution in order to generate reasonable scattered

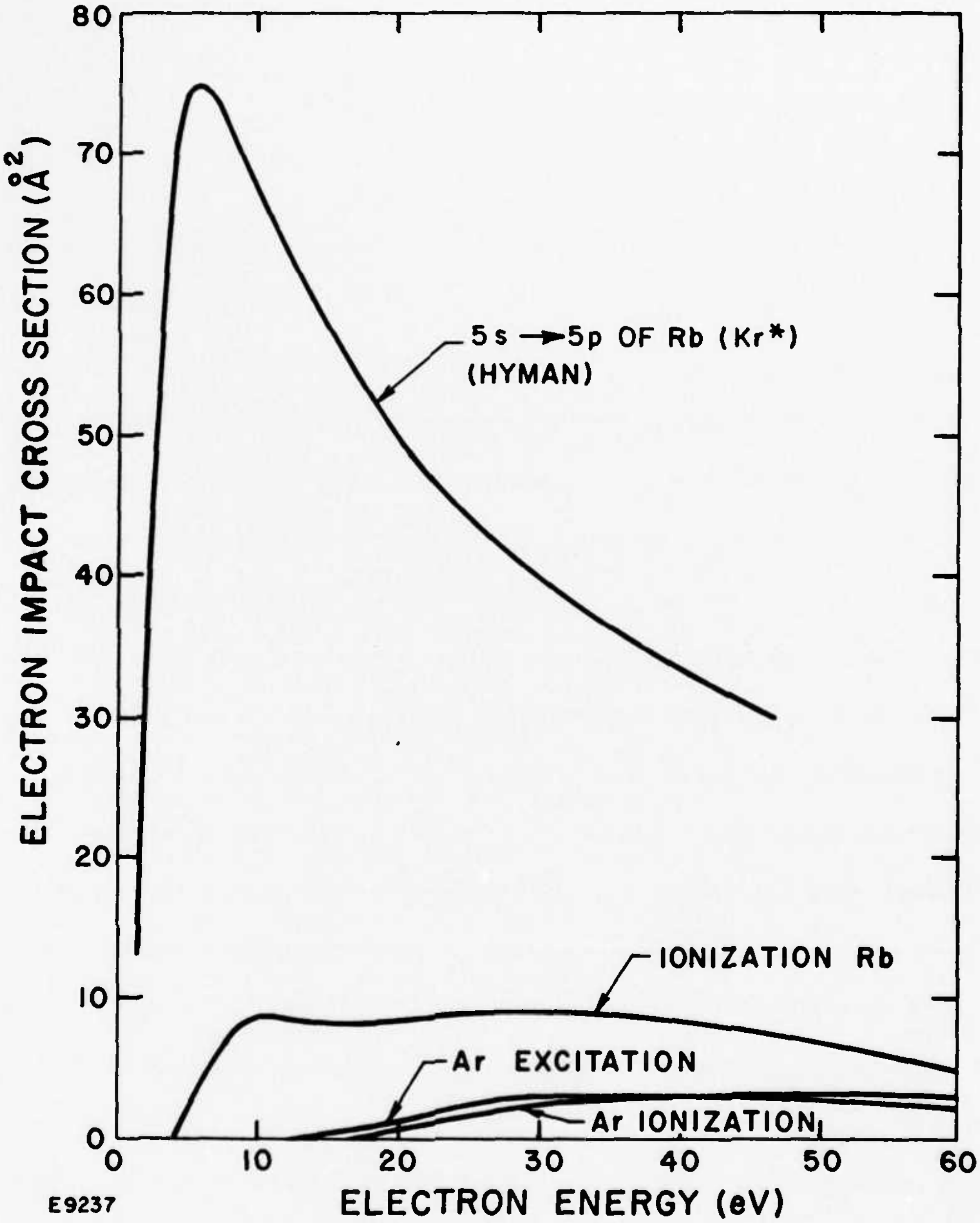


Figure 4 Electron Impact Cross Section for Rb (Kr*) and Ar as a Function of Electron Energy

electron currents from the metastable scattering species whose density in the beam is anticipated to be rather low.

During the previous contractual periods an electron spectrometer was constructed and shown to obtain satisfactory energy loss spectra for electron scattering processes from ground state rare gases. During the present period of performance emphasis has been placed upon establishing a satisfactory signal-to-noise ratio in order to handle the extremely small signals anticipated in the metastable scattering experiments. In addition consideration has been given to which type of metastable source best suits the requirements of this experiment and various sources have been constructed and tested.

B. ELECTRON SPECTROMETER

As previously stated the emphasis of the work related to the electron spectrometer was associated with producing an acceptable signal-to-noise level for the metastable scattering experiment.

Recently the cross section for excitation from the 5s configuration to the 5p configuration in rubidium has been estimated by Hyman and is shown in Figure 5. Since the krypton metastable atom is similar to ground state rubidium in terms of atomic structure this transition should be similar to the corresponding 5s to 5p transition of interest in metastable krypton. The important point, once again, is the large magnitude of the cross section, ~ 75 Å^2. Shown also in Figure 5 for comparison are the ionization cross sections for rubidium and the excitation and ionization cross sections for argon. From Figure 4 it is clear that the peak value of the "metastable" cross section is 30 times the peak value of the argon excitation cross section. The important consequence of the relative magnitudes and energy

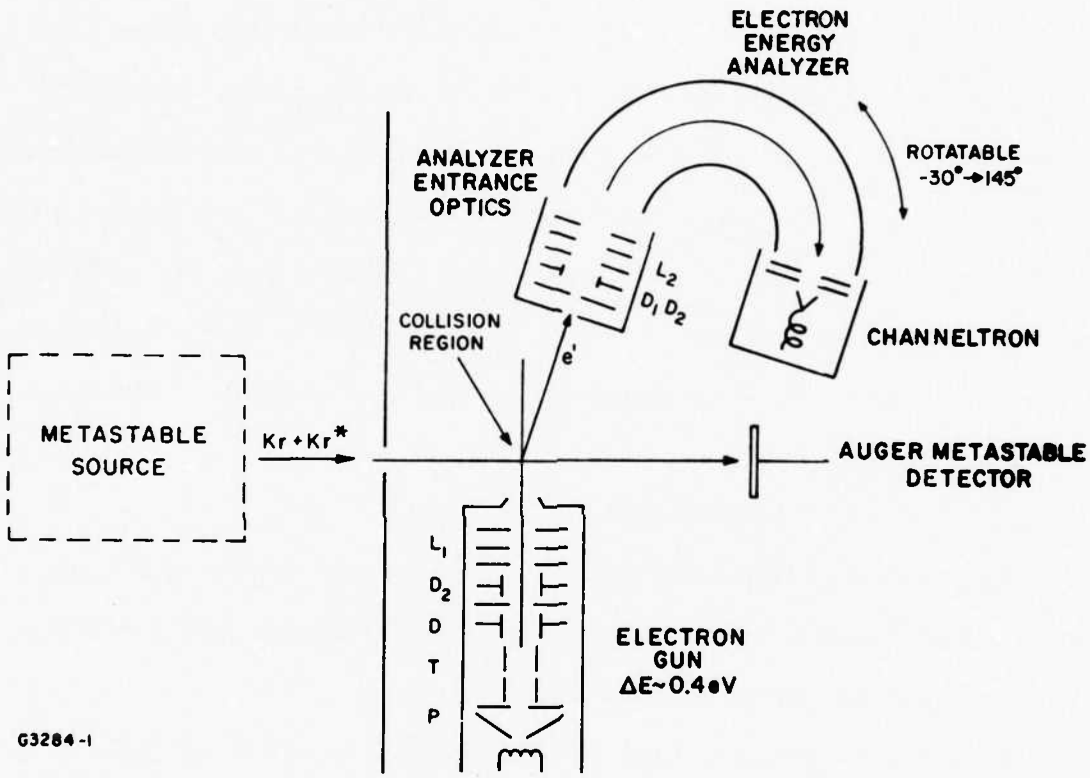


Figure 5 Schematic of the Crossed Beams Apparatus for Electron Scattering from Metastable States of Rare Gases

dependance of these cross sections as far as discharge pumping of the rare gas halide lasers is concerned is that most of the electrons can excite the 5s to 5p transitions in argon which has a threshold of 1.6 eV whereas only the high-energy tail of the electron energy distribution can produce metastables from the ground state.

For the Krypton experiment we shall be interested in observing energy loss processes in the region of 1.6 eV, (see Figure 1). Observations of the energy loss spectrum in this region indicated an unacceptably large signal level due in part to the wing of the incident electron beam and to a much larger extent a background signal arising from scattered electrons suffering inelastic collisions with surfaces. A great deal of effort has been directed towards reducing the inelastically surface-collisions component of this signal. A sophisticated electron collector containing baffles and retaining electrodes has been constructed and installed in the experiment for the purpose of collecting and retaining the incident electron beam after passage through the collision region. The angular capability of the collector extends from 20° to 135°. The forward direction is limited by the physical size of the analyzer entrance optics.

A schematic of the cross section of the electron collector is shown in Figure 6. The primary electron beam is shown entering the collector from the left after diverging from a focus at the point C where it has intersected the atomic beam. The collector is designed to ensure that multiple reflections from various surfaces must occur before an electron could exit from the collector. Baffles B are placed at the entrance to further reduce the probability of escape.

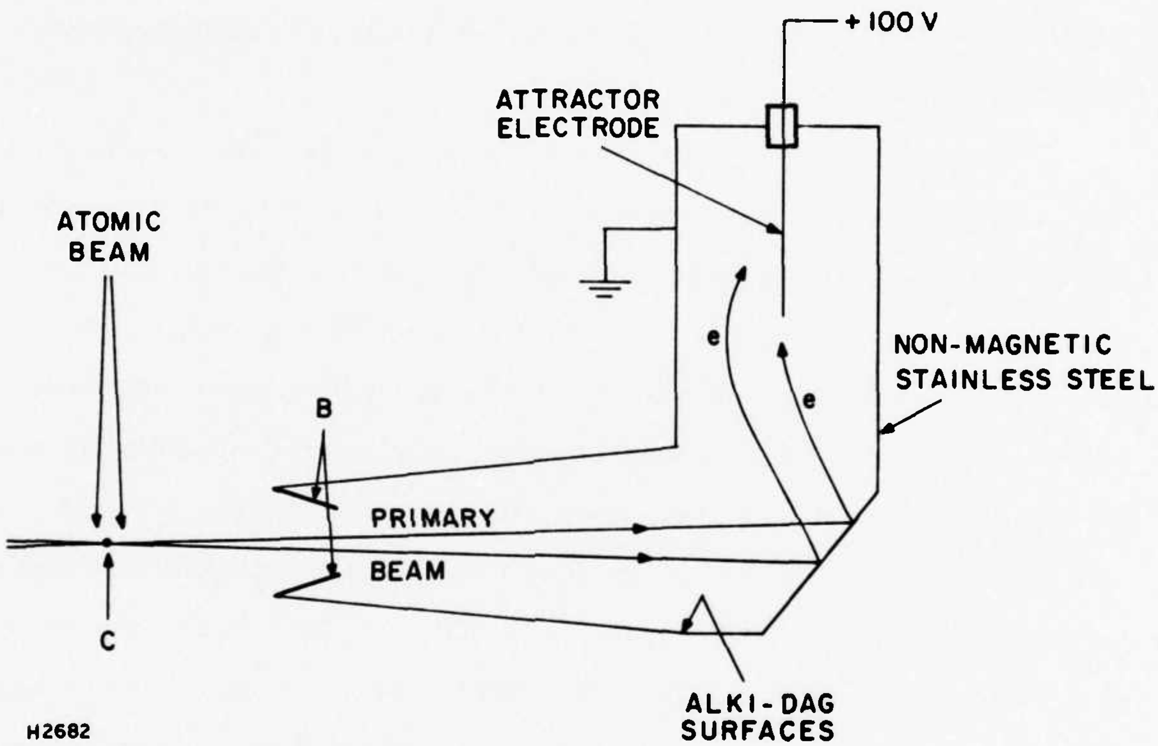


Figure 6 Schematic of the Cross Section of the Primary E-Beam Collector

An attractor electrode is placed out of the line of sight of the collision region and biased + 100 V with respect to the collector. The purpose of this electrode is to attract electrons to the upper portion of the collector in order to decrease their probability of escape and eventually to act as a sink for the electrons. The collector is constructed from 0.010" thick non-magnetic stainless steel and the interior surfaces are coated with Alki-Dag, a colloidal suspension of graphite in alcohol which possesses a low secondary electron emission coefficient.

Various cones and baffles have been introduced to improve the detection capability in the angular range below 20°, however reducing the scattered incident electron beam intensity by the required twelve orders of magnitude has not proved feasible and measurements will therefore be confined to the angular range above 20°.

The angular profile of the primary beam has been determined in the following manner. The beam is first focused tightly on the scattering volume by adjusting the gun controls for maximum scattered signal at some arbitrary angle. The gun is then rotated to zero degrees and the primary beam collected on the outer hemisphere of the electrostatic analyzer simply by reversing the sign of the potential normally applied. Minor adjustments are made to the beam steering plates to optimize the current. Figure 7 shows the profile of the beam as measured on the outer hemisphere as the gun is slowly rotated. The measurement is eventually limited by small leakage currents to the outer hemisphere which obscure the primary beam. However it is event that over the angular range 0 to 5° the beam intensity falls by three orders of magnitude. Beyond 5° the profile develops a sort of skirt which can be followed out to 8° the limit of measurement due

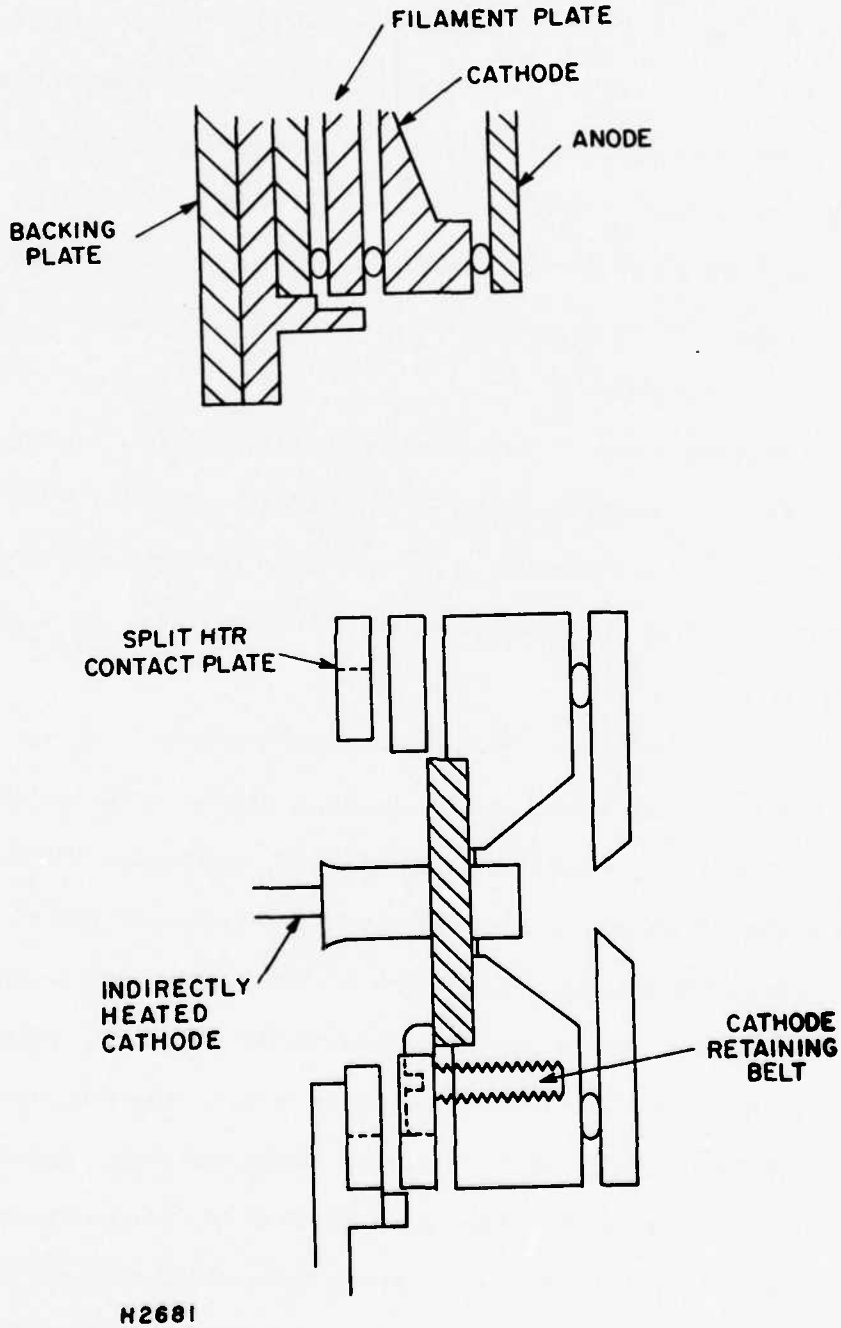


Figure 7 Design of the Indirectly Heated Cathode Holder

to the leakage currents. It is very likely that part of the background at 1.6 eV energy loss and at angles below 20^o could be due to the wing of the direct beam scattering off the entrance optics, losing energy, and appearing as a continum in the loss spectrum.

The performance of the spectrometer in terms of its angular scattering behavior has been evaluated. Various ealstic scattering measurements have been performed in the angular range 25^o - 110^o for a wide range of incident energies for both He and Ar. In the case of He comparison with accurate existing theoretical and experimental data indicates that the accuracy of the angular dependences measured is better than 20%.

As mentioned previously the 5s to 5p transition in krypton has an energy loss of $\sim$ 1.6 eV and hence in the energy loss spectrum of scattered electrons this process will be indicated by a peak located 1.6 eV from the elastic scattering peak. The electron collector has successfully reduced the background of inelastically scattered electrons in this energy loss region to acceptable levels at least in the angular range above 20^o. The residual background in the energy loss region is due mainly to the wing of the elastic scattering peak. The spread in electron energies in the elastic scattering peak arises principally from a combination of the thermal emission distribution from the filament together with potential variations across the filament emission area. These effects could be reduced by replacing the directly heated thoria - coated filament with an indirectly heated cathode. The indirectly heated cathode emits a lower temperature which reduces the thermal spread and furthermore removes the potential drop effect since the cathode is a unipotential surface. This replacement procedure requires modification to the electron gun cathode region and is currently in process.

The design of the indirectly heated cathode holder is shown in Figure 8. The cathode is an RCA barium oxide cathode imbedded in a sintered matrix and mounted on a molybdemum cylinder which is in turn attached to a 1/2" diameter ceramic disc. The emission area of the cathode is 1/8" diameter.

C. METASTABLE SOURCE

At the commencement of this program period the decision was taken to implement two parallel metastable source investigations, namely a glow discharge technique and a charge exchange source.

1. Charge Exchange Source

Charge exchange cross sections for collisions between rare gas ions and alkali metals are known to exhibit extremely large cross sections. Since the alkali metal ionization potential is near resonant with the ionization potential of the corresponding metastable rare gas then it is to be expected that these charge exchange collisions are likely to produce copious amounts of metastable states of the rare gas.

The principle of the scheme is illustrated in Figure 9. As indicated the total cross section for charge exchange collisions between argon ions and rubidum vapor was measured by Peterson and Lorents to be of the order $10^{-14} cm^2$. However, they were not able to investigate the state distribution of the neutral argon atoms. More recently Nevnaber and Magnuson have repeated the experiment with post collision state identification. Their results are summarized in the lower half of Figure 9. For those species investigated a large fractional population of the metastable state was observed.

Currently a duoplasmatron ion source is being modified to be compatible with the experimental apparatus. The anticipated experimental arrangement is shown in Figure 10. An Einzel lens arrangement focuses

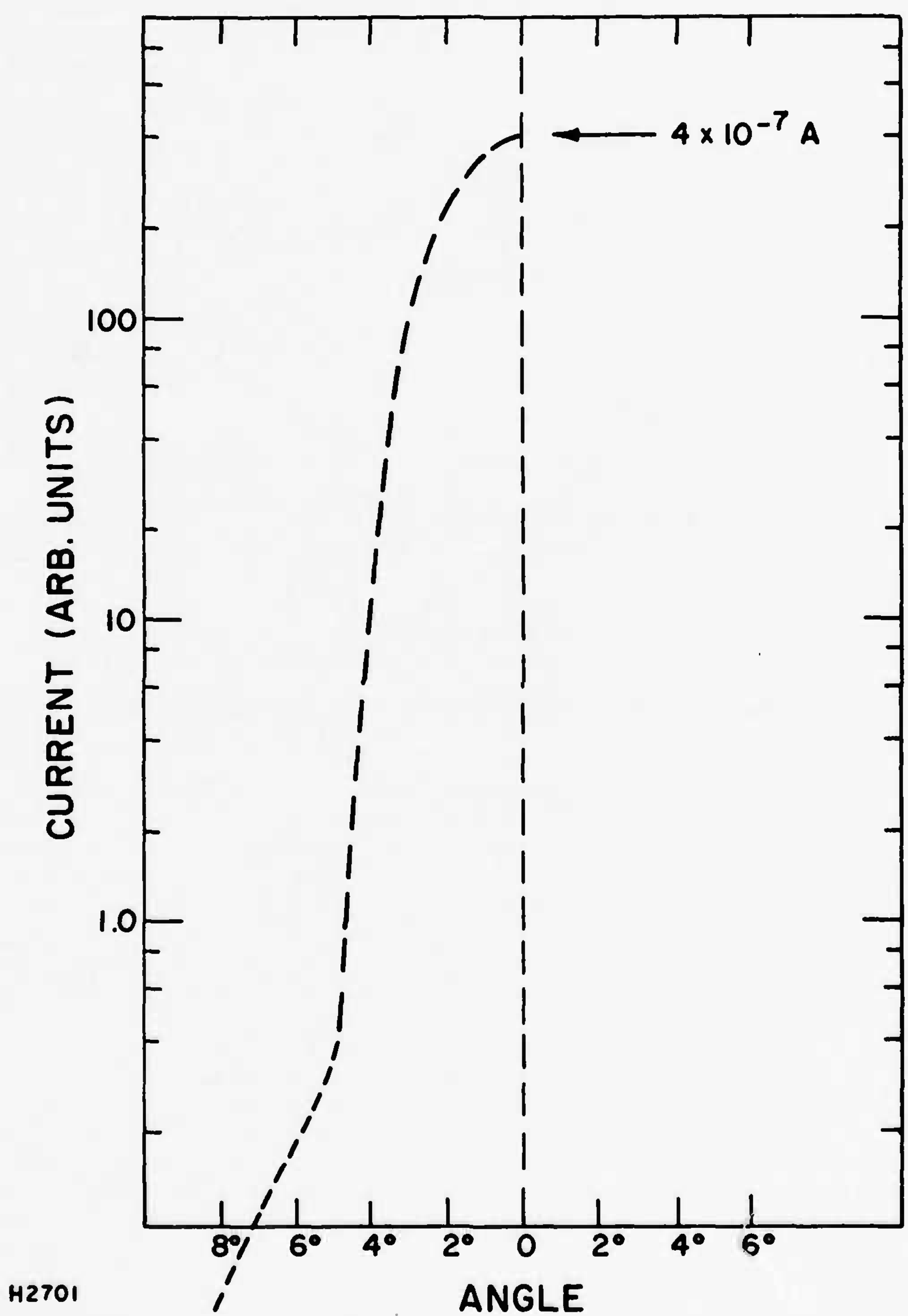
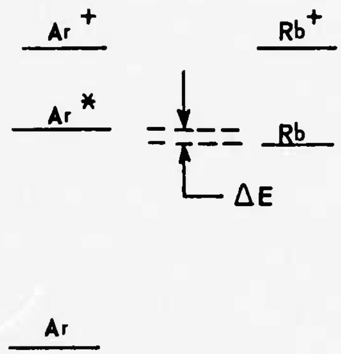


Figure 8 Primary E-Beam Angular Profile



$$Ar^{+} + Rb \longrightarrow Rb^{+} + \begin{cases} Ar^{*} \\ Ar \end{cases}$$

$$\sigma \sim 1.5 \times 10^{-14}\ cm^2$$

(J.R. PETERSON & D.C. LORENTS, PHYS REV, 182, 152, (1969))

BRANCHING RATIOS, γ

RARE GAS X	ALKALI	$\gamma = \frac{X^*}{X + X^*}$
He	Cs	0.85
Ne	Na	0.5
Ar	Rb	0.4

(R.H. NEYNABER & G.D. MAGNUSON, J. CHEM. PHYS. 65, 5239, (1976))

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Figure 9 Charge Exchange Leading to Excited State Formation

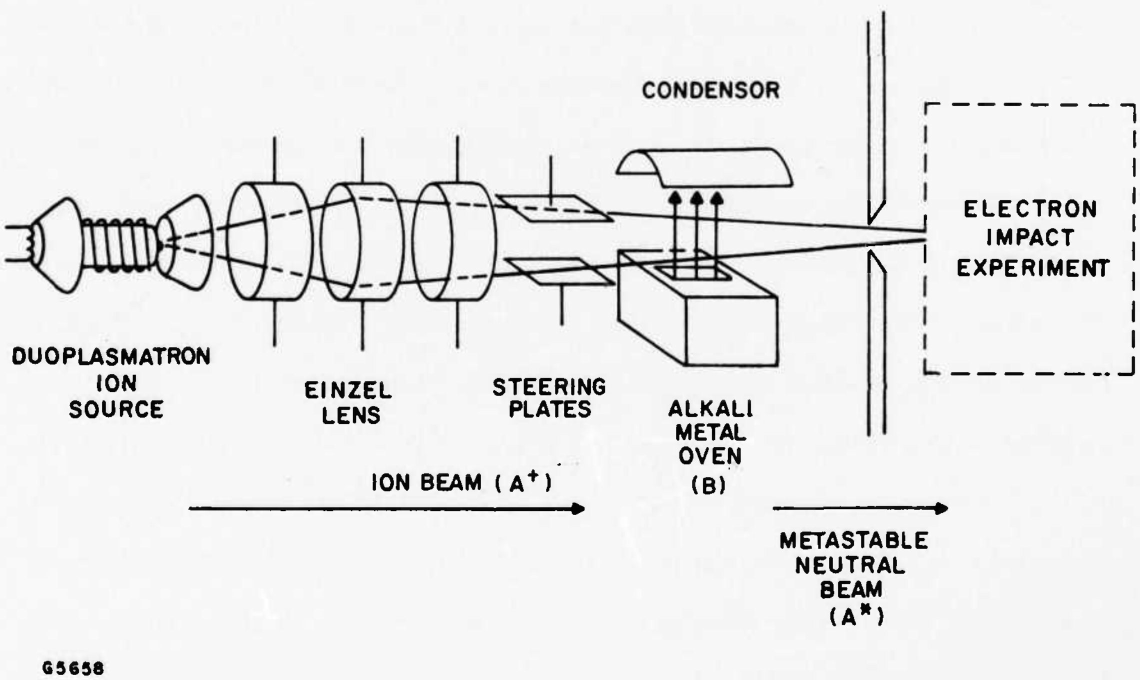

Figure 10 Schematic of the Charge Exchange Apparatus for Metastable Rare Gas Production

the ion beam extracted from the duoplasmatron ion source into the collision region of the electron spectrometer. The trajectory of the ion beam prior to the electron impact is intercepted by a region of alkali metal vapor in the pressure region of 10^{-4} torr. Steering plates are provided to control the ion beam trajectory. In order to produce excited state densities of the order 10^{-10} cm^{-3} it is anticipated that ion beam intensities of the order 0.5 mA will be required. Once the duoplasmatron has been modified experiments will commence for the purpose of measuring the ion current capabilities in order to assess the suitability of this ion source for the charge exchange experiment. A duoplasmatron ion source and Einzel lens assembly was purchased from Physicon Corporation though usually operated in the higher energy region (tens of kilowatts) the manufacturer expects the source to be capable of supplying the necessary current of 0.5 mA of krypton at 5 kV.

A circuit diagram including a schematic of the source is shown in Figure 11. A dense plasma is produced using a directly heated filament and confined by a magnetic field generated by a solenoid. The ions are extracted from the plasma sheath by an extractor electrode and pass through the eizel lens assembly which focuses the beam and determines the final energy. Since lateral beam control is extremely important two pair of perpendicular deflector plates are currently being installed beyond the eizel lens.

2. Glow Discharge Source

Experiments have been performed with variety of glow discharge sources and attempts will be made to introduce various features into the design which optimizes metastable atom production and minimizes energetic photon production. The latter is undesirable since the photons liberate secondary electrons once they collide with surfaces in the experimental region and hence contributes to the noise background.

PHYSICON ION SOURCE

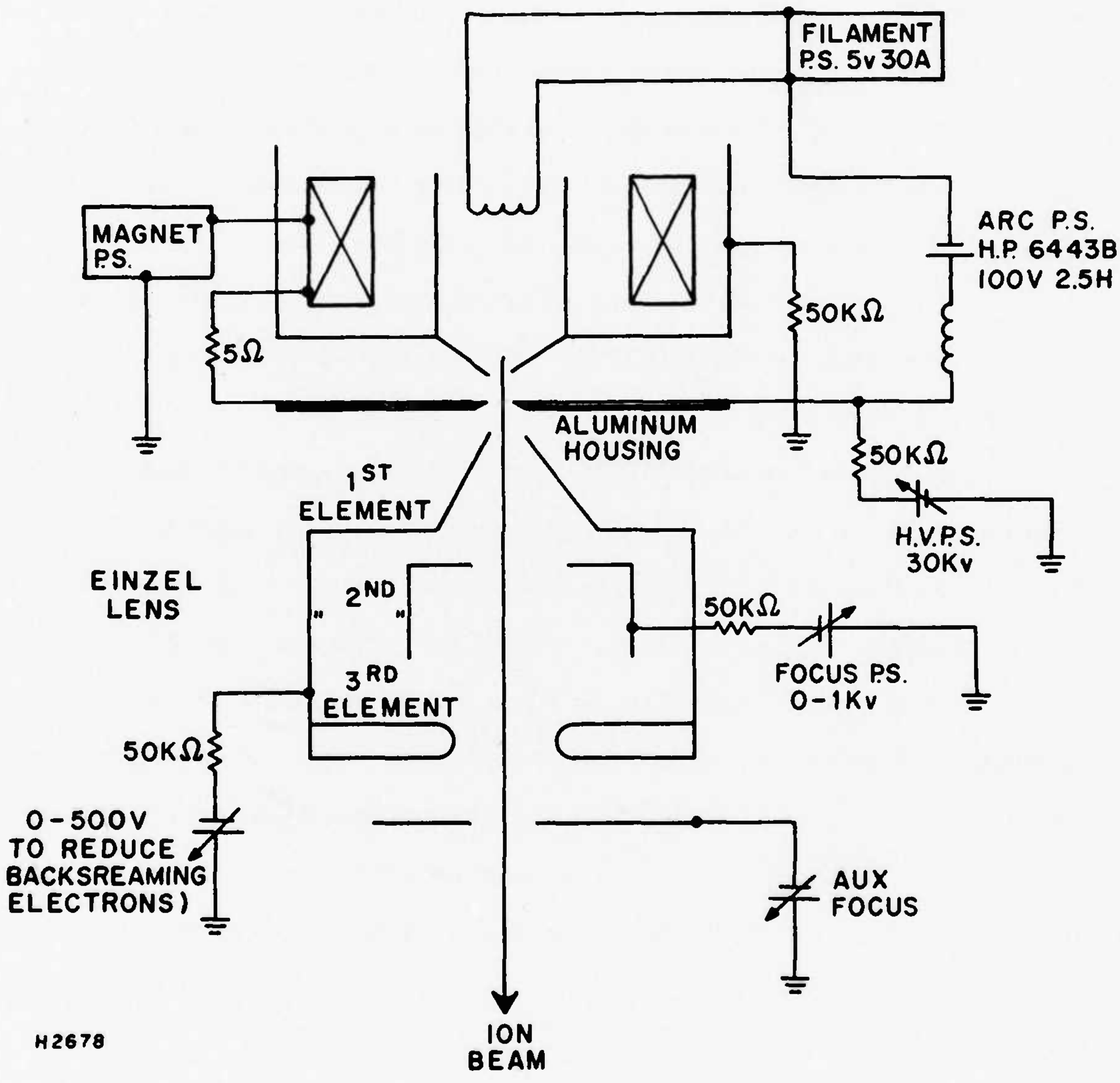

Figure 11 Circuit Diagram of the Duoplasmation Ion Source

Such a glow discharge source is illustrated in Figure 12. The particular source shown is a modified He-Ne laser, it is located in a separately pumped chamber and communicates with the main chamber via a 0.050" dia orifice. Several insulated plates containing larger apertures are placed immediately beyond the end of the discharge tube opening. Various bias potentials can be applied to these plates in order to reflect charged particles from the beam and also to quench high lying Rydberg states.

An Auger detector has been designed and installed in the vacuum system. The main components of the detector and the operating circuit are shown in Figure 13.

The detector operates on the Auger principle, namely that metastable atoms possessing excitation energy in excess of the work function of a metal surface may liberate electrons from that metal surface upon impact with it. Usually a highly transparent grid is placed above the metal surface and biased positively with respect to the surface so that the ejected electrons are completely removed. If the secondary emission coefficient for the particular metastable and the particular surface are known then by measuring the current leaving the surface the metastable flux can be estimated. The guard plates ensure high electrical insulation since small currents are normally encountered and the deflector plates are to remove any remaining charged particules from the beam.

Noise suppression from the source was initially a major problem since this noise coupled with the sensitive channeltron multiplier used for the electron scattering detector. By suitably rejecting the charged particle component of the beam and efficiently shielding high-voltage leads, etc., the noise has been reduced to an acceptable level.

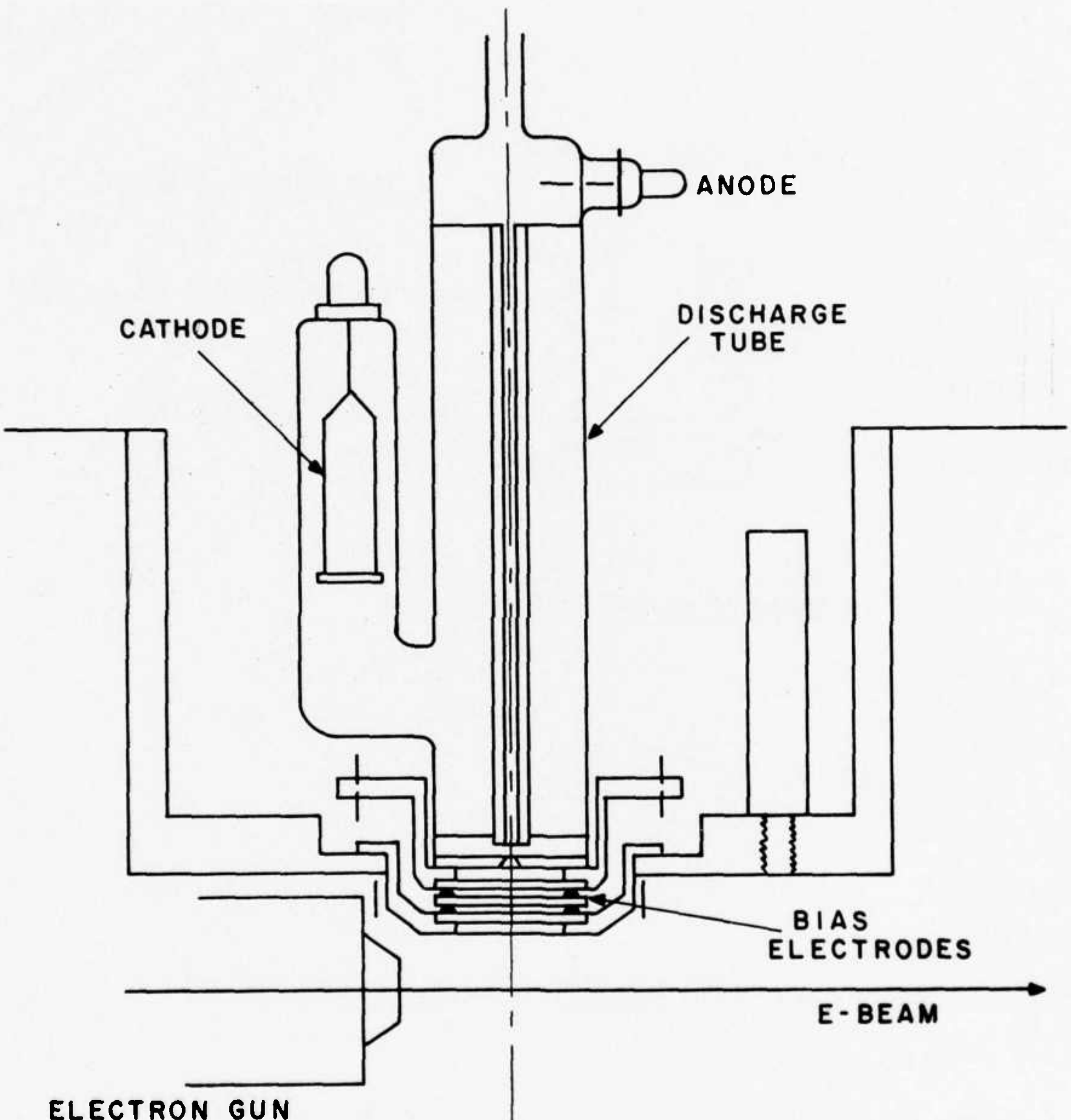

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Figure 12 Schematic of a Glow Discharge Source Employed for Metastable Rare Gas Production

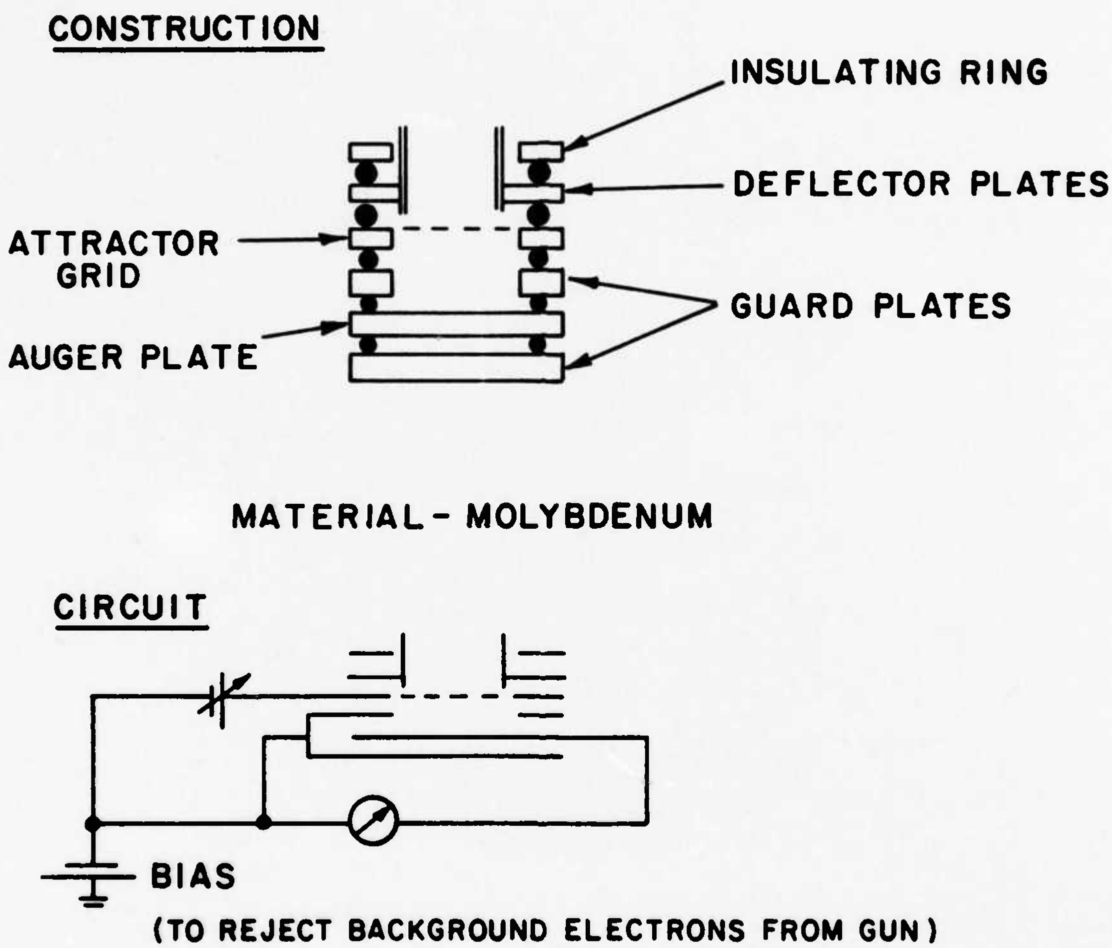

Figure 13 Schematic of the Auger Detector and Operating Circuit

Since energetic photons may also liberate electrons from the surface of the Auger detector gas attenuation experiments must be performed in order to reveal the composition of the beam arriving at the Auger detector. These experiments are incomplete but will be reported in the next semi-annual report.

III. ELECTRON IMPACT EXCITATION OF METASTABLE ARGON AND KRYPTON: THEORY

The Born cross section for electron impact excitation of an atom from initial state i to final state f is given by

$$\sigma_{if} = \frac{8}{k_i^2 \, \Delta E} \int_{K_{min}}^{K_{max}} \tilde{f}_{if}(K) \, \frac{dK}{K} \, (\pi a_o^2) \tag{1}$$

where k_i^2 is the energy of the incident electron, ΔE is the excitation energy, and K is the momentum transferred during the collision. $\tilde{f}$ is the generalized oscillator strength (GOS) and is given by the expression

$$\tilde{f}_{if}(K) = \frac{\Delta E}{k^2} \, \frac{1}{g_i} \sum \left| \langle f \left| e^{i\bar{K}.\bar{r}} \right| i \rangle \right|^2 \tag{2}$$

with g_i the degeneracy of the initial state and the sum extending over all degernate levels of the initial and final states.

Due to the importance of spin-orbit effects in the rare gases, the cross sections must be calculated in the intermediate coupling scheme, which is the representation in which both the electrostatic and spin-orbit interactions are diagonal. The intermediate-coupled wavefunction for the kth state can be expanded in pure LS-coupled states as follows:

$$\left| \ell^\epsilon \ell_k \Gamma_k J_k M_k \right\rangle = \sum_{S_k L_k} \left| \ell^\epsilon SL \ell_k S_k L_k J_k M_k \right\rangle \left\langle \ell^\epsilon SL \ell_k S_k L_k J_k \right| \left. \ell^\epsilon \ell_k \Gamma_k J_k \right\rangle \tag{3}$$

In terms of these wavefunctions, the GOS can then be written as

$$\tilde{f}_{\Gamma_i J_k, \Gamma_f J_f}(K) = \frac{\Delta E}{2J_i + 1} \frac{4\pi}{K^2} \sum_{\lambda} \left| \sum_{S_i L_i} \sum_{S_f L_f} \langle \Gamma_f J_f \left| S_f L_f J_f \right\rangle \right.$$

$$\left. \langle S_f L_j J_f \| j_\lambda Y_\lambda \| S_i L_i J_i \rangle \langle S_i L_i J_i \left| \Gamma_i J_i \right\rangle \right|^2 \tag{4}$$

with the reduced matrix element given by

$$\langle S_f L_f J_f \quad j_\lambda Y_\lambda \quad S_i L_i J_i \rangle = \delta_{S_i, S_f} (-1)^{S_i + L_i + J_f + L + \ell_i + L_f + \ell_f}$$

$$\times \sqrt{\frac{(2J_i + 1)(2J_f + 1)(2L_i + 1)(2L_f + 1)(2\ell_i + 1)(2\ell_f + \quad)(2\lambda - 1)}{4\pi}} \tag{5}$$

$$\times \begin{Bmatrix} L_f & J_f & S_i \\ J_i & L_i & \lambda \end{Bmatrix} \qquad \begin{Bmatrix} \ell_f & L_f & L \\ L_i & \ell_i & \lambda \end{Bmatrix} \qquad \begin{pmatrix} \ell_f & \lambda & \ell_i \\ 0 & 0 & 0 \end{pmatrix} \quad R_\lambda(K)$$

and where

$$R_\lambda(K) = \int_0^\infty P_{n_f \ell_f}(r)\, j_\lambda(Kr)\, P_{n_i \ell_i}(r)\, dr \tag{6}$$

$P_{n\ell}(r)$ is the radial wavefunction for the configuration and $j_\lambda(Kr)$ is the sperical Bessel function of order λ. In general, the coefficients $\langle \Gamma J | SLJ \rangle$ are determined by diagonalizing the spin-orbit interaction in the LS-coupled basis states and fitting the resultant energies to the experimental level structure.

It is also of interest for laser modeling to consider an effective or average cross section between configurations, which will be defined as the sum over final levels, $\Gamma_f J_f$, and average over initial levels, $\Gamma_i J_i$. If it is assumed that the various terms in each configuration are degenerate, which is a reasonable approximation for the problem of interest, then expression (4) can be formally summed to yield the required cross section. Using the unitarity properties of the $\langle \Gamma J\ SLJ \rangle$ coefficients and the well-known orthogonality properties of the 6-J symbol, the effective cross section can be written as

$$\bar{\sigma}_{if} = \frac{8}{k_i^2} (2\ell_f + 1) \sum_{\lambda} \left[(2\lambda + 1) \begin{pmatrix} \ell_i & \lambda & \ell_f \\ 0 & 0 & 0 \end{pmatrix}^2 \int_{\bar{K}_{min}}^{K_{max}} R_{\lambda}^2 (\bar{K}) \frac{d\bar{K}}{\bar{K}^3} \right] \tag{7}$$

with all qualities defined as before, and with K representing the average momentum transfer.

The principal problem in the evaluation of the various quantities given above is the specification of the radial wavefunction. In order to calculate the wavefunction we have used a method originally due to Vainshtein,[10] in which the radial Schrodinger equation for the optical electron is written in the form

$$\left[\frac{d^2}{dr^2} - \frac{\ell(\ell + 1)}{r^2} + \frac{2}{r} Y \left(\frac{r}{a_k} \right) + E_k \right] P_k(r) = 0 \tag{8}$$

$Y(\rho)$ is the effective charge and is constructed from the ionic Hartree-Fock functions of Clementi and Roetti.[11] The energy, E_k, is then taken to be the experimental energy of the kth state, and the equation is solved for the eigenvalue a_k and corresponding eigenfunction $P_k(r)$. The parameter a_k

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(10) Vainshtein, L.A., Opt. Spect. 3, 313 (1957).

(11) Clementi, E. and Roetti, C., Atomic Data and Nuclear Data Tables 14, 177 (1974).

acts as a radial scaling factor and thus compensates for various small effects, such as exchange, induced polarization of the core, etc., that are omitted from the Schrodinger Eq. (8). Since the wavefunction corresponds to the exact energy, the present scheme should give accurate values for the radial integrals of Eq. (6).

To be more specific, we show in Figure 6 a partial energy level diagram for the excited states of argon (the corresponding krypton energy level diagram is very similar). The excited states have the form Ar^* $(\ldots\ 3s^2\ 3p^5\ n\ell;\ J)$, where $n\ell$ denotes the orbital of the excited electron and J is the total angular momentum. In intermediate coupling only J and parity are good quantum numbers. In the first excited configuration, $n\ell = 4s$ and there are four substates: $J = 0, 2$ are metastable, while the two $J = 1$ levels radiatively decay to the ground state. The next higher configuration is $n\ell = 4p$ with ten J-states. Cross sections for the 4s; $J \rightarrow 4p; J'$ array (and the corresponding 5s; $J \rightarrow 5p; J'$ array for Kr^*) will be determined in intermediate coupling using Eqs. (1) to (6). To the right of the figure are the statistically averaged energy levels for the configuration, determined according to the formula.

$$\bar{E} = \sum (2J + 1)\ E_J / \sum (2J + 1) \tag{9}$$

with the sum extending over all J-states of the configuration. The corresponding average binding energies, $I - \bar{E}$ (where I is the ionization potential), are the values used in Eq. (8) for E_k; these values in units of Rydbergs (1 Ry = 13.6 eV), are listed in Tables I and II for argon and krypton, respectively. In the last column of each table we list the calculated values of the scaling parameter, α_k, determined by numerically solving the

TABLE I BINDING ENERGIES AND SCALING PARAMETERS FOR Ar*

State	Average Binding Energy (Ry)	Scaling Parameter (α)
$3s^2 3p^5 4s$	-0.30627	1.2718
4p	-0.19464	1.2343
3d	-0.12740	1.2490
5s	-0.12376	1.2512
5p	-0.09183	1.2204
4d	-0.07174	1.2383

TABLE II BINDING ENERGIES AND SCALING PARAMETERS FOR Kr*

State	Average Binding Energy (Ry)	Scaling Parameter (α)
$4s^2 4p^5 5s$	-0.29700	1.2245
5p	-0.18593	1.1915
4d	-0.13321	1.2228
6s	-0.12006	1.2012
6p	-0.08867	1.1796
5d	-0.07312	1.2104

Schrodinger equation [(Eq. 8)] subject to the boundary conditions: $P_k(0) = 0$ and $P_k(r) \to 0$ for large r. The fact that the α's are not too different from unity and that the total range is $1.18 \le \alpha_k \le 1.27$ lead us to believe that our central-field model gives a good representation for the excited states. The wavefunctions, $P_k(r)$, corresponding to the eigenvalues α_k, will be used to calculate the required cross sections from the formulas given above.

IV. PRESENT STATUS

During this period of performance the emphasis of the experimental program has been directed towards reducing the background signal arising from electrons scattered inelastically from surfaces. This was eventually accomplished by the design of an efficient electron collector which collects the primary electron beam immediately after transit through the collision region. With this collector an acceptable background noise level can be maintained to scattering angles as low as 20°. Below this angle the analyzer entrance optics physically obstructs the beams and makes efficient collection of the beam difficult.

Progress is being made in the design of metastable sources. Both the charge transfer and glow discharge techniques are being explored. In principle the charge transfer scheme appears capable of producing higher densities of metastable rare gases however in practice the glow discharge source is considerably more simple to implement. Experiments have been performed with a number of glow discharge sources and an optimized design is close to being achieved. Measurements of metastable production efficiency are in progress.

On the theoretical aspect of the problem the wavefunctions corresponding to the eigenvalues will be used to calculate the required cross sections from the formulae given in the text.

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